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RUMFORD AND THE TEAPOTS - DEMONSTRATION OF THE
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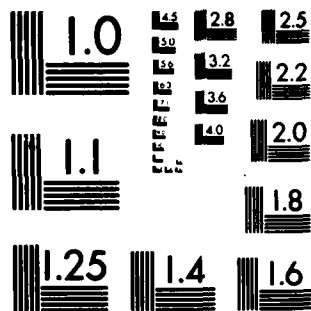
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**ROYAL SIGNALS & RADAR
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**RUMFORD AND THE TEAPOTS – DEMONSTRATION OF THE
FORMATION OF THERMAL IMAGES**

**Authors: E H Putley and
D E Burgess**

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ROYAL SIGNALS AND RADAR ESTABLISHMENT

Memorandum 3528

Title: RUMFORD AND THE TEAPOTS - DEMONSTRATION OF THE FORMATION OF THERMAL IMAGES

Authors: E H Putley and D E Burgess

Date: January 1983

SUMMARY

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A modern version of an experiment originally performed by Count Rumford is described. This enables us to demonstrate some of the factors concerned in the formation of thermal images. The images obtained with a pyroelectric vidicon thermal imager are compared with the visible images to demonstrate the effects of the surface characteristics of the objects in the scene. Demonstrations of transmission and reflection effects using a modified Leslie cube are also included.

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RUMFORD AND THE TEAPOTS - A DEMONSTRATION OF THE FORMATION OF THERMAL IMAGES

E H Putley and D E Burgess

CONTENTS

- 1 INTRODUCTION
- 2 COUNT RUMFORD'S EXPERIMENT
- 3 DEMONSTRATION WITH A THERMAL IMAGER
- 4 THERMAL GLINT AND REFLECTION EFFECTS
- 5 CONCLUSION
- 6 ACKNOWLEDGEMENT

REFERENCES

FIGURE CAPTIONS

1 INTRODUCTION

Thermal Imagers are able to form the images of scenes because the thermal emissions from different elements of the scene as viewed by the imager differ from each other. The primary factor responsible is difference in temperatures between the corresponding elements but differences in the emissivity of the surfaces of the elements can have a significant effect. The emissivity depends upon the nature of the surface and for many real surfaces also upon the angle of incidence. Moreover the behaviour is further complicated by the relation between emissivity and reflectivity. A low emissivity surface will have a high reflectivity and this can result in the total radiation received from a given element being much greater than that emitted directly by it.

It is sometimes difficult in a typical scene to demonstrate, let alone quantify, the significance of these factors. By recalling an experiment first performed by Count Rumford in 1807⁽¹⁾ and adapting it for study with a thermal imager we have attempted to demonstrate some of these effects and to show ways in which thermal and visible images differ.

2 COUNT RUMFORD'S EXPERIMENT

Rumford was one of the first to draw attention to the importance of the surface on the rate of emission of thermal radiation. Rumford's work was carried out at the same time but independently of Leslie whose cube experiment is probably the best known demonstration of surface characteristics. Rumford was very concerned with the practical application of science and he soon applied his results to the design of fire places and cooking utensils. His interests was attracted to the fact that many of his well-to-do friends used silver tea pots

because, they claimed, these made better tea than porcelain ones. Rumford wished to investigate this to establish whether there was any truth in this claim or whether it was merely an affectation. Rumford's investigation is described in a paper read at the Institute de France on August 12th, 1807⁽¹⁾. He obtained a pair of similar porcelain vessels, one plain white and the other gilded. Filling them both with boiling water he noted that the gilded one cooled much more slowly than the plain one thus demonstrating that a vessel with a metallic surface retains its heat longer and so vindicating the claims of the owners of the silver teapots.

Rumford's experiment has been repeated in a number of slightly different forms. One demonstration used a pair of metal saucepans, one brightly burnished and the other blackened with soot and used a differential air thermometer or a thermocouple to measure the temperature difference to establish that the bright one cools the more slowly⁽²⁾.

Tyndall observed directly the difference in emission from the two vessels by means of a thermopile⁽³⁾. Using a thermal imager we can now observe instantly this difference. The results obtained also show reflection effects which are not directly apparent using non-imaging apparatus and which led to confusing results in some of the early attempts to measure emissivity.

3 DEMONSTRATION WITH A THERMAL IMAGER

For his original experiment Rumford had a pair of porcelain vessels specially prepared by a Parisian manufacturer. With the kind cooperation of the Royal Worcester Porcelain Company we obtained the pair of coffee pots shown in figure (1)*. One is in plain Worcester porcelain whilst the other is finished in brilliant gold lustre, that is a fired-on film of gold. Thermal observations were made using a pyroelectric vidicon thermal imager⁽⁴⁾ (The colour plate A shows the apparatus used whilst plates B and C show a demonstration in progress). Figure (1b) is the thermal image obtained after both pots were filled with boiling water and allowed to stand for about half an hour. The thermal imager indicates white - hot, black - cold so that a literal interpretation of the picture would suggest that the gold pot was cooler than the plain one. In fact measurement with a thermometer or testing with the hand shows that by this time the gold one is appreciably warmer than the plain one. The figure suggests however that parts of the gold one are emitting strongly. This is not the case, but what we are seeing is reflections of radiation from the plain one by the highly reflecting gold surface. The picture shows also the reflection of the radiation in the polished table top on which the pots are placed and radiation from the warmed table mats on which they are standing directly. That this explanation is correct is demonstrated by figures (1c) and (1d) which show the effect of placing a sheet of plate glass between the pots. Glass is opaque to thermal radiation and so it eliminates the radiation from the plain pot reflected in the gold one and also the reflection of this reflected radiation in the table top but not of course the direct reflection from the plain pot in the table top. Finally to show how thermal imagers reveal information not shown by the visible, the hot water was emptied from the plain pot and it was half-filled with lukewarm water, (figures (1e) and (1f)). The thermal picture shows the water level clearly. At this point the hand could be placed on it without discomfort but the gold lustre one was still too hot to touch.

* In the figures the left-hand pictures are visible whilst the right hand thermal

A further demonstration is afforded by the group of three teapots shown in figure (2). The centre one is Worcester gold lustre whilst the left one is Worcester porcelain and the right hand one Worcester manufactured bone china. The first thermal picture (figure (2b)) shows that there is no significant difference between the radiative properties of the two plain teapots and a pattern of reflections is seen as would be expected from figure (1b). Figures (2c) to (2f) demonstrate the difference between the optical and thermal transmission of several materials. Figures (2c) and (2d) show a polished germanium lens blank 10 cm diameter and 2 cm thick standing on a vee block in front of the central teapot. This material is used for the infrared lenses used in thermal imagers and other IR apparatus but it is completely opaque to the visible. Thus in figure (2c) it completely obscures the view of the central pot but in (2d) only the vee block can be easily seen.

In figures (2e) and (2f) a sheet of black polythene as used in rubbish bins and the sheet of plate glass shown in figures (1c) and (1d) have been placed in front of the left and right hand teapots respectively, with the germanium remaining in the centre. These figures show that glass is opaque in the infrared but the polythene is relatively transparent. The polythene attenuates the radiation somewhat and this reveals that the signal obtained earlier has been saturating the camera with loss of detail for it is now possible to see the water level in the teapot. In examining very hot industrial equipment it is important to guard against this effect and thus losing useful information.

A third group is shown in figure (3). This consists of (from left to right) a common earthenware, an embossed chromium plated metal pot and an enamelled iron one. Figure (3b) shows that the thermal characteristics depend primarily on the surface finish and not on the material of the pots. The earthenware and enamel ones appear similar to the porcelain ones and the chromium one has a low emissivity comparable to the gold lustre finished porcelain. Figures (3c) and (3d) show the effect of inserting cards between the pots to reduce reflection effects. This shows that the chromium plated pot has a significant emission at re-entrants at the junction of the spout with the main body and between the rim and the lid and also at indents in the embossed pattern round the centre of the pot. These features illustrate how multiple reflections combine to increase the emission from an enclosed surface which in a completely enclosed space becomes total black body radiation that is not dependent on the nature of the enclosing surfaces.

4 THERMAL GLINT AND REFLECTION EFFECTS

To show more clearly thermal glints or hot spots from low emissivity metallic bodies the three teapots shown in figure (4) were used. The plain aluminium one on the right does not show any body pattern unlike the left hand embossed chromium plated one but it shows marked emission from the base of the spout where there is a deep groove associated with the construction. Clear thermal reflections of both these pots are seen in the Worcester porcelain gold lustre one placed to the rear and slightly higher. It is noticeable that the more smoothly flowing lines of the ceramic pot do not give rise to glints in contrast to the more angular features in the metal ones. It is not clear whether these metallic glints are produced entirely by geometrical effects or whether the presence of oxidation or foreign deposits in the cavities increases the emissivity. Probably both factors contribute. In either case, to avoid the effect careful surface design is necessary.

Further examples of reflection effects are shown in figure (5). Figures (5a) and (5b) show a copper cube with a chequer pattern painted on one side, using black, white and army green paints and leaving some squares polished

copper. The cube was filled with hot water. In front of the cube is placed the germanium lens blank used previously. The thermal picture (5b) shows that all the painted squares emit at a comparable (high) rate but the polished copper squares emit much less. The aperture of the thermal camera was reduced to show the slight transmission loss of the germanium. In pictures (5c) and (5d) the chequered face of the cube is turned to one side. The side facing the camera has alternate polished and lacquered stripes which are clearly differentiated in the thermal picture. The main interest is the germanium disc which is placed on the chequered side at approximately 45° to the axis. The chequered pattern reflected by the disc is clearly seen. Unbloomed germanium (as this disc was) has a reflectivity of about 60%. This picture demonstrates the desirability of using properly bloomed surfaces for germanium optical components, but it was set up principally to demonstrate a further type of thermal artefact. This configuration is used in beam splitters in interferometers and in multi-spectral instruments. By placing a thermal source behind the germanium we could superimpose the reflected image onto one directly seen and thus create the thermal analogue of Pepper's Ghost.

5 CONCLUSION

Comparison of the corresponding visual and thermal images in the figures shows that the common factor relating the visible to the thermal is the correspondence of shape. The visual and thermal images differ in many relatively minor details but this does not affect our ability to recognize or identify familiar objects. However the thermal images contain highlights associated with geometrical structures of the objects and reflection effects depending upon the proximity of neighbouring objects. Although these features do not impair our recognition capabilities they have a significant bearing on any attempt to extract quantitative information from the observed emittance patterns. In the pictures shown here the origin of these effects is self-evident but in a more complex scene a highlight could be misinterpreted as some kind of heat leak such as a flaw in a furnace wall. Thus it is important that users should be aware of these effects. They depend only on the nature of the scene not on the characteristics of the thermal imager. Thus users, those concerned with thermal flow and heat conservation applications in particular, must be fully aware of these possibilities when interpreting their results and more importantly when planning a programme of observations.

6 ACKNOWLEDGEMENT

We wish to thank the Board of Directors of the Royal Worcester Porcelain Company and Mr David West, Technical Manager, for kindly providing examples of Worcester Porcelain ware used in these demonstrations.

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RUMFORD AND THE TEA POTS

Illustrations

Title

Plate A	General view of apparatus
B	Demonstration in progress (1)
C	Demonstration in progress (2)
(1)	Pair of Royal Worcester coffee pots
(2)	Group of Royal Worcester tea pots
(3)	Earthenware and metal pots
(4)	(Upper pair) Group of metal pots
(5)	(Lower four) Transmission and Reflection

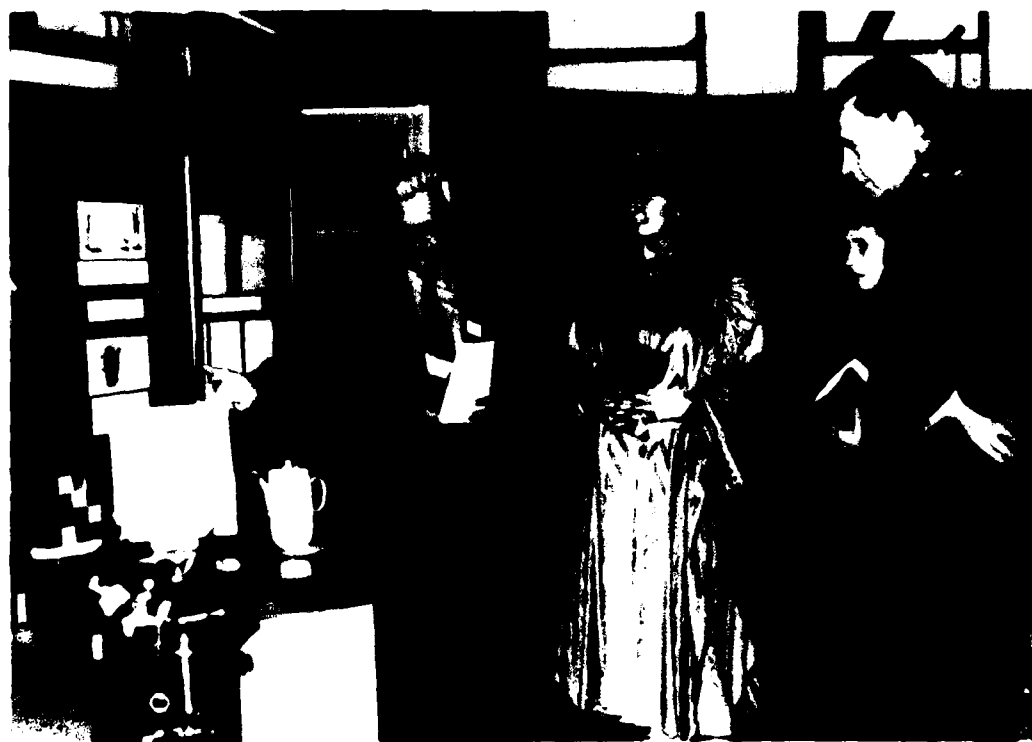
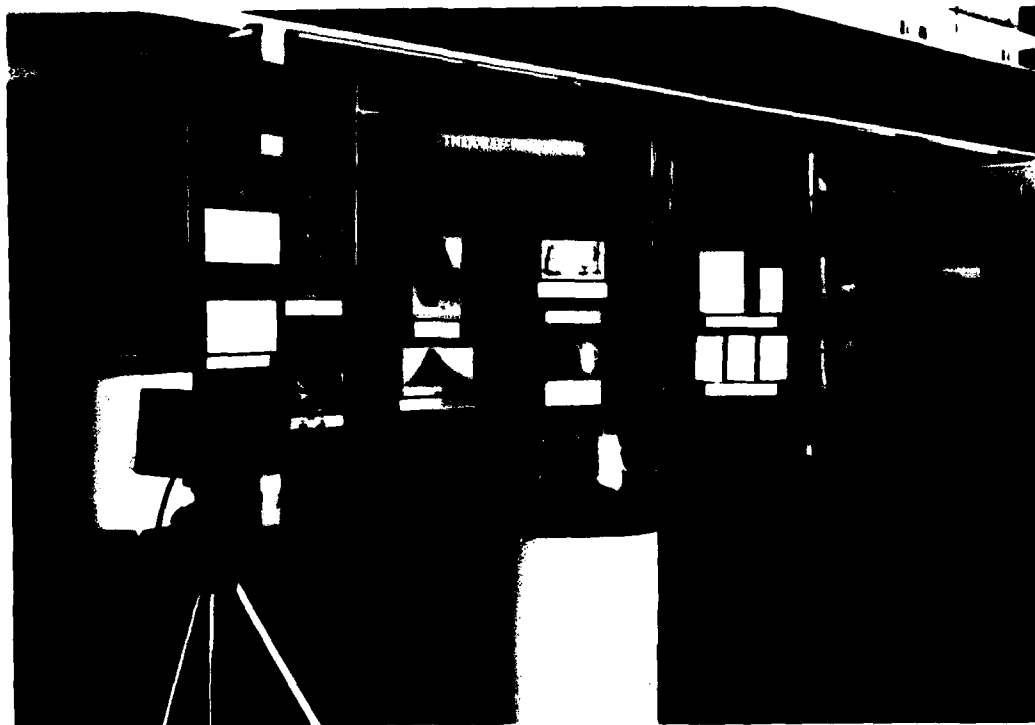
FIGURE CAPTIONS

- A General view showing pyrovidicon camera on left, pair of Royal Worcester coffee pots centre. Background display on the history of infrared.
- B Demonstration 23 September 1982. E H Putley explaining experiment to Mrs Dunne, Mrs Sharp and Captain Dunne, Lord Lieutenant of Hereford and Worcester. Note chequer painted Leslie cube extreme left. The gold lustre pot is obscured by body of pyrovidicon camera.
- C Demonstration 23 September. E H Putley showing to Captain Dunne and D Hampton that black polythene transmits IR.
- (1) Royal Worcester Porcelain coffee pots. The right hand one is plain undecorated porcelain whilst the left hand one is finished with a thin layer of fire-on gold (gold lustre). The top pair of picture, (a) and (b), compare visible and thermal images when both pots are filled with hot water. The radiation from the gold lustre pot is significantly less than that from the plain one even though when the picture was taken its temperature was several °C higher. The apparent hot spots on the gold lustre pot are reflections from the plain one. This is demonstrated by the centre pair of pictures, (c) and (d), where a sheet of plate glass has been placed between the pots. This is opaque to infrared and it suppresses the radiation transmitted from the plain pot and reflected in the lustre one. It therefore also suppresses the reflection of this reflected radiation in the polished table top. The lower pair of pictures, (d) and (e), were taken with the plain pot half-filled with lukewarm water. The thermal camera can be adjusted to show the water level. This technique can be used for the remote examination of oil tanks or storage tanks containing warm liquids.

- (2) Royal Worcester tea pots. Centre finished in gold lustre, left hand Worcester porcelain, right hand bone china. The thermal picture (RHS) show that there is no significant difference in the thermal emission of the two plain pots. Reflection effects similar to those noted in figure (1) are also seen. The lower group of four pictures demonstrate the infrared transmission of various materials. The centre pictures (c) and (d), show a polished germanium infrared lens blank placed in front of the lustre pot. This is completely opaque in the visible but highly transmitting in the infrared.

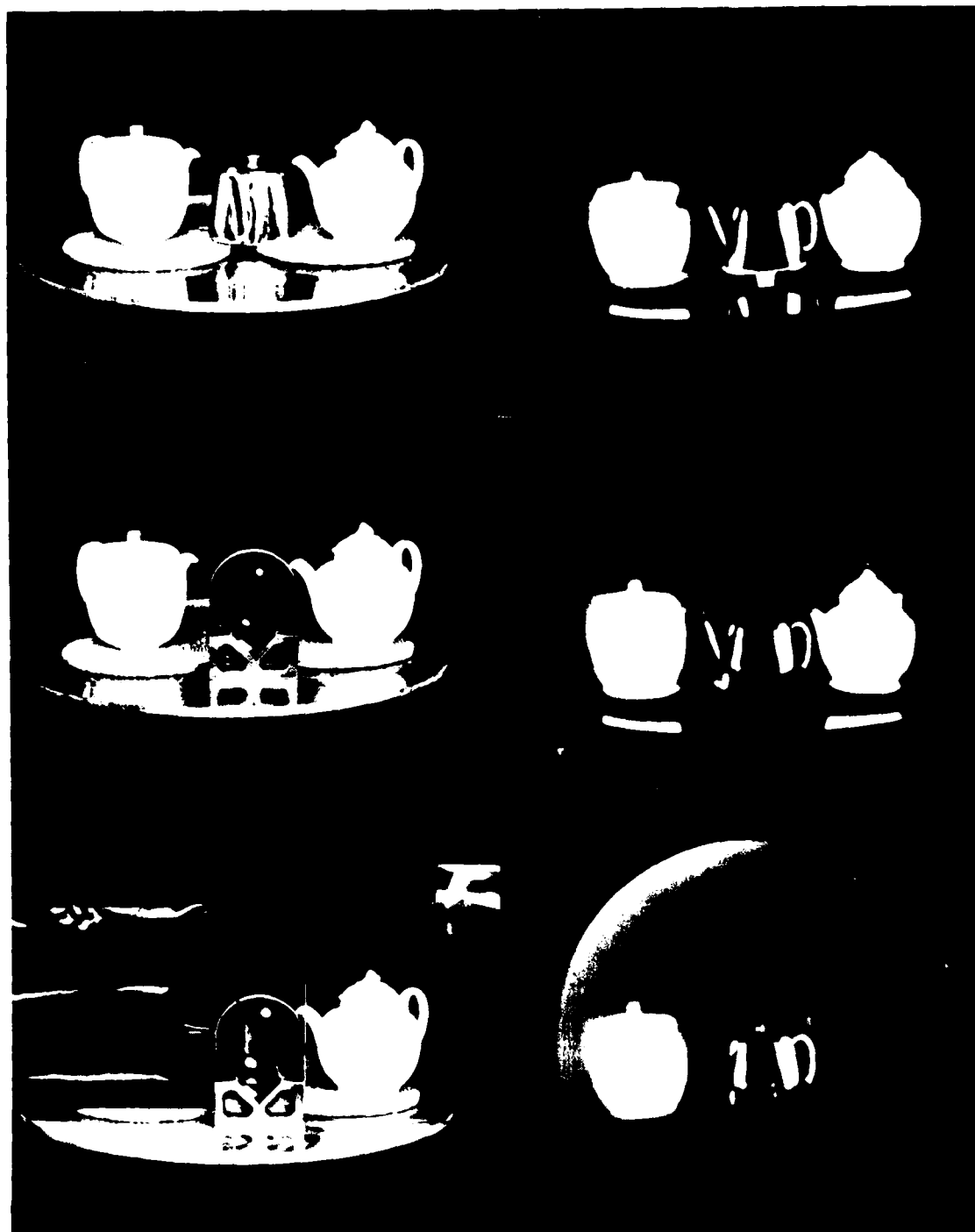
The bottom pair of pictures, (e) and (f), show on the left hand side a sheet of black polythene and on the right hand side the sheet of plate glass shown in figures (1) (b) and (c). Comparison of the visible and thermal pictures shows that the glass transparent in the visible is opaque in the infrared but the black polythene is opaque in the visible and transparent in the infrared.

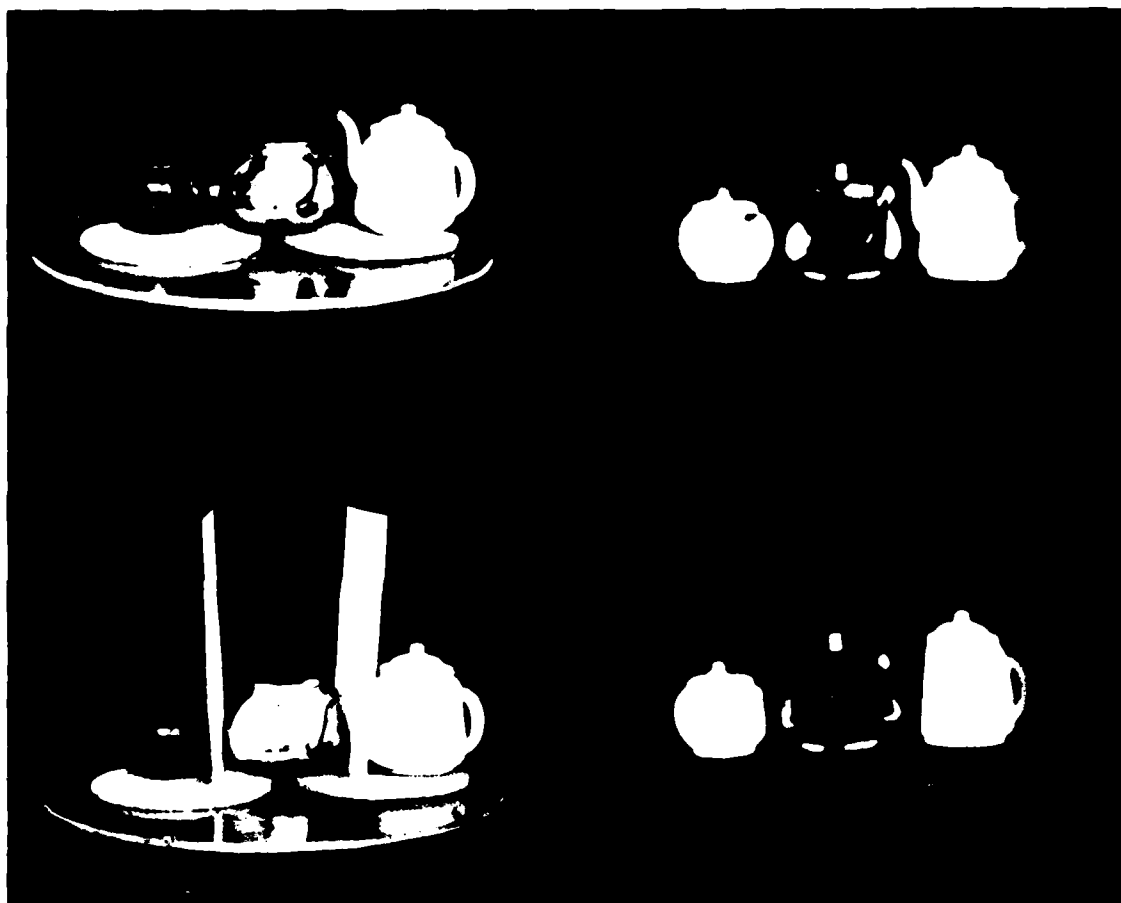
- (3) Everyday tea pots. The left hand one is earthenware, the centre chromium plated and decorated with embossed designs and the right hand one enamelled iron. These pictures demonstrate that earthenware and enamel are good emitters but the chromium surface is comparable to gold except that the cavities caused by the embossing radiate significantly. Reflection effects will again be noted which in the lower pair of pictures are suppressed by placing cards between the pots.
- (4) Metal tea pots. In this pair of pictures three metal surfaced pots are grouped together. Left the decorated chromium one used in (3), centre the gold lustre one seen in (2) and right a plain aluminium pot. Because they all radiate at a significantly lower level than the ceramic pots the aperture of the thermal camera could be opened up to show more detail in the thermal picture. Reflections in the table top and the reflections of the two outer pots in the centre gold lustre one can be easily recognised. Radiation from depressions in the metal surface such as the embossed pattern on the left hand pot and the joint between the body and the spout of the plain aluminium pot is clearly seen. Radiation from the plastic handles and knobs on the lids is clearly much greater than that from the bodies of the pots, as is also the radiation from the tea pot stands (which were actually clay pigeons in this picture).
- (5) Transmission and Reflection. A modified Leslie cube is used with the germanium lens blank used also in (2) (c), (d), (e) and (f). One face of the cube is painted in a chequer pattern using black, white, and army green paint with some squares polished metal (see plate B). In the thermal picture the colours are indistinguishable but the base metal appears black (low emissivity). In the top pair of pictures the germanium blank is placed in front of the chequered side. Its outline is seen in the thermal picture demonstrating that it is not perfectly transparent. In the lower pair of pictures the chequered face has been turned to one side and the lens blank placed at approximately 45° to reflect it towards the camera. The side of the cube facing the camera has alternate stripes plain metal and lacquered. The thermal picture shows the reflection in the germanium's surfaces. The apparent blurring of the reflected image is caused by the overlapping of the reflections in the front and rear faces of the lens blank.

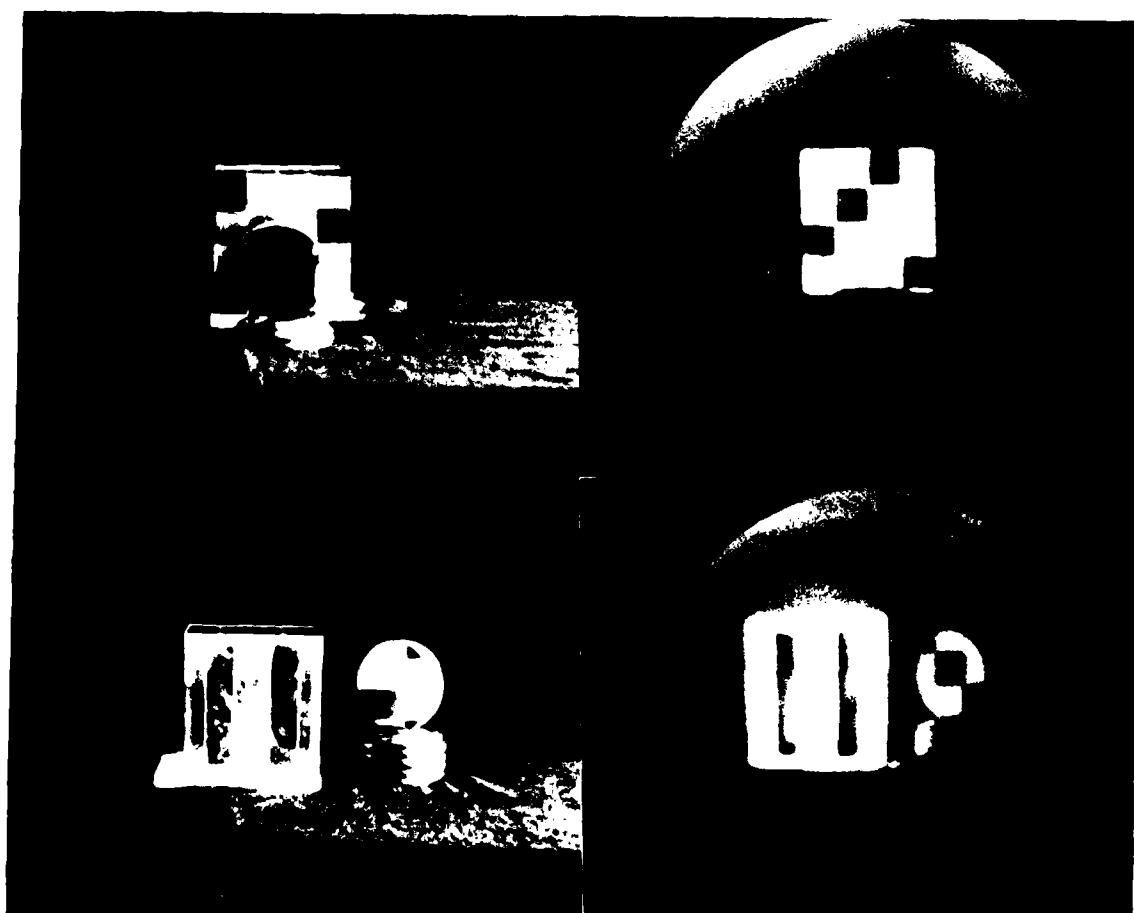
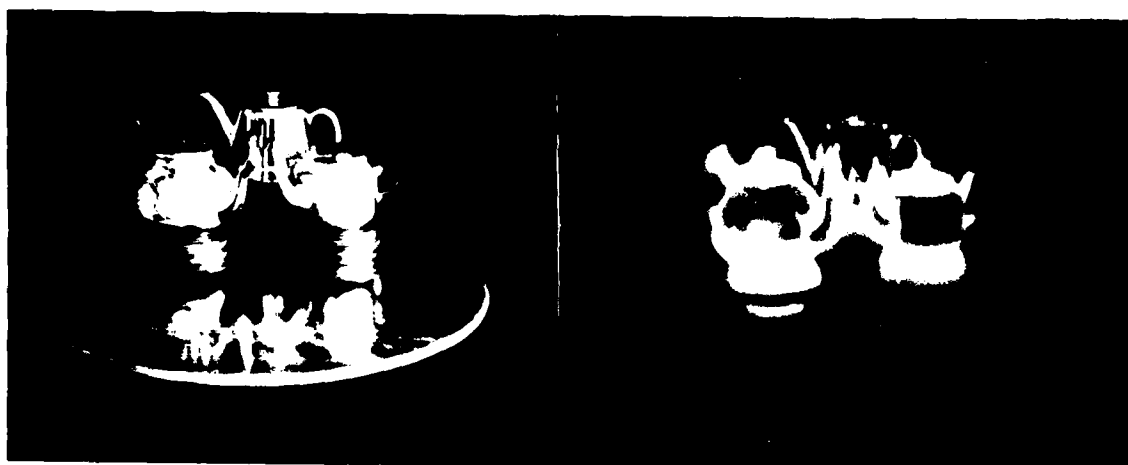












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Abstract A modern version of an experiment originally performed by Count Rumford is described. This enables us to demonstrate some of the factors concerned in the formation of thermal images. The images obtained with a pyroelectric vidicon thermal imager are compared with the visible images to demonstrate the effects of the surface characteristics of the objects in the scene. Demonstrations of transmission and reflection effects using a modified Leslie cube are also included.				